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MAXIMIZING WATER USE EFFICIENCY OF MAIZE CROP IN SANDY SOILS

[33]

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ABSTRACT

Field experiment was conducted in private farm, El-Bustan region, Beheira Governorate for three seasons (1998,1999 and 2000) to investigate presurized irrigated maize crop management (Single cross 10).Drip and sprinkler irrigation systems were selected. Three water application rates (50,75 and 100% of ETc) and two irrigation intervals (daily irrigation and irrigation every three days) were tested in this experiment. The results of this study can be summarized as follow:

1- Actual water consumptive use and seasonal irrigation water requirements were lower by (13.7% and 22.6%) than calculated values using the climatic data under both sprinkler and drip irrigation system.
2- The highest grain yield (4.24 Mgram/fed) was produced under drip irrigation system compared to sprinkler irrigation system (3.36 Mgram/fed).
3- The best maize yield was when 100% of ETc was applied under both drip and sprinkler irrigation systems compared with 50 and 75% of ETc treatments
4- Daily irrigation gave the highest yield of maize compared to irrigation every three days.
5- The lowest cost of maize production unit was (64.6LE/Mgram) under drip irrigation system when 100% of ETc daily was applied, while the highest cost was 308.8LE/ton under sprinkler irrigation system when 50% of ETc every three days was applied.
6- Water production functions of maize crop under both drip and sprinkler irrigation were:

For sprinkler irrigation system

Daily irrigation	$Y= 2x10^{-7}X^2 - 2x10^{-5}X +0.38$
Irrigation every 3rd day	$Y= 2x10^{-7}X^2 - 4x10^{-4}X +0.66$

For drip irrigation system

Daily irrigation	$Y= 6x10^{-7}X^2 - 0.0012X +2.26$
Irrigation every 3rd day	$Y= 7x10^{-8}X^2 - 0.0007X +0.33$

Y is the yield in Mgram/feddan, and X is amount applied water in m^3/feddan.

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INTRODUCTION

The maize cultivated area around the world has been increased, even under arid conditions where irrigation must be practiced. In arid and semi-arid areas one of the most important limiting factors in maize production is the amount of available water for irrigation. The irrigation cost in these areas is increasing and for this reason farmers are forced to maximize the water use efficiency of their crops. To reach these optimum levels of efficiencies, modern irrigation systems and proper irrigation management must be used.

Clark (1979) compared the relative efficiencies of trickle, sprinkler and furrow irrigation for corn production. He found that the water use efficiencies of 0.014, 0.0119 and 0.0115 Mg/ha-mm with three respective systems. **El-Gindy (1984)** reported that the average yield for furrow and drip irrigated sweet pepper were 2.35 and 2.75 kg/m^2 while, the water use efficiencies were 3.21 kg/m^{3}and 5.8 kg/m^3 under furrow and drip irrigation respectively. **Safontas and Di Paola (1985)** reported that the maize grain yield increases of up to 35% with drip irrigation as compared to sprinkler irrigation system. **El-Gindy (1988)** reported that the yield of tomato increased under drip irrigation by 33% and 35% over the furrow and sprinkler systems and by54.5% and 154.9%over the furrow and sprinkler irrigated cucumber. **Kamal (2000)** said that the maximum value of maize yield was 1.725 ton/fed under surface drip irrigation ,while the minimum value was 1.504 ton/fed under sprinkler irrigation system.

Yamamoto (1991) reported that in humid areas as Japan, the advantages of the drip irrigation with daily irrigation compared to sprinkler irrigation with three days of irrigation intervals were, the soil content was held higher than field capacity in the main root zone and evaporation loss from the sandy surface was a little smaller, but the yield and water use efficiency was higher. **Caldwell *et al* (1994)** reported that corn yields were excellent under daily irrigation (11.9 to 12.5 Mgram/fed) regardless of whether a frequency of 1, 3, 5 or 7 days was used for subsurface drip irrigation system. **El-Moweelhi *et al* (1999)** found that when increasing irrigation intervals from 4 to 7 days, the maize ear weight decreased by 19.2% under drip irrigation system in clay soil. **Lamm *et al* (1995)** reported that the management of surface drip irrigation can reduce net irrigation needs by 25% while still maintaining top corn yield of 12.5Mg/ha.

Lyle and Bordovsky (1995) found that the corn yield increased from 8.3 to 12.4 Mg/ha by increasing the water application rate from 0.4 to 1.3 of evapotranspiration. On the other hand, the highest corn grain yield was obtained with three and six day irrigation intervals (11.1 Mg / ha) under sprinkler irrigation compared to 9and12 day with furrow irrigation. **Helmy *et al* (2000)** found that drip irrigation system saved about 41% of irrigation water and increased the water use efficiency by 43.8% for corn crop compared to the furrow irrigation. **Kassem (2000)** reported that amount of

the applied water under drip irrigation system was less than that under furrow irrigation. Also, amount of the applied water decreased by increasing the irrigation intervals from one to three days.

The aim of this paper is management of pressurized irrigation systems for maximizing water use efficiency of maize crop in sandy soils.

MATERIAL AND METHODS

1. Experimental site

Field experiment was conducted in pravite farm in El-Bustan Region, Beheira Governorate for three seasons (1998, 1999 and 2000) on maize crop (Single cross 10), the preceding crop was faba bean for the three seasons. The soil is sandy and the plant row spacing was 75cm, while the distance between plants in row was 20cm. The experimental design was split-split plot and the plot area was $300m^2$ (15x20m). Soil physical and chemical properties and chemical analysis of irrigation water are presented in Tables (1, 2 and 3).

2. Irrigation system

Two irrigation systems were selected to irrigate maize plants. The first is surface built in drip lines system (GR, 4 lph discharge at 1.0 bar operating pressure and 50cm emitters spacing. 16mm laterals as used at75cm spacing. The second system is sprinkler irrigation. The sprinklers spacing were 12x12m with discharge of $1.0m^3/h$ at 2.5bar operating pressure. The layout of irrigation systems is shown in Fig. (1).

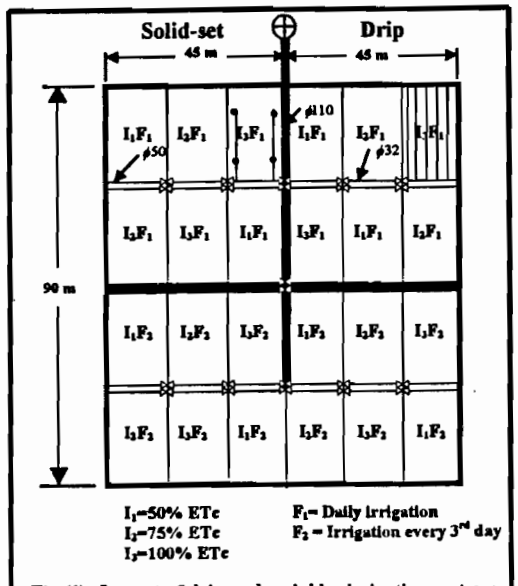

Fig.(1): Layout of drip and sprinkler irrigation systems

Table 1. Physical properties of sandy soil.

Sample depth	Particle Size Distribution %				F.C.	W.P.	B.D.	Texture Class
	C. Sand	F. Sand	Silt	Clay				
0-30	52.8	41.4	4.1	1.7	9.4	4.3	1.68	Sandy
30-60	50.0	43.5	5.0	1.5	8.5	4.4	1.57	Sandy

Table 2. Chemical properties of Sandy soil.

Sample depth	pH	EC dS/m	Soluble Cations meq/L				Soluble Anions meq/L			
			Ca	Mg	Na	K	CO_3	HCO_3	SO_4	CL
0-30	8.2	1.27	2.9	2.8	5.1	0.6	-	3.6	2	6.1
30-60	8.3	1.22	2.9	2.1	5.2	0.7	-	3.7	2.1	6.3

Table 3. Chemical analysis of irrigation water.

pH	EC dS/m	Soluble Cations in meq/L				Soluble Anions meq/L			SAR
		Ca	Mg	Na	K	HCO_3	SO_4	CL	
7.74	0.55	1.03	0.74	8.01	0.42	1.95	4.52	3.73	8.51

3. Water application rate

Three water application rates were applied for irrigating the maize crop (I_1=50%, I_2=75% and I_3=100% of water consumptive use (ETc)). Water consumptive use was calculated according to the climatic data recorded at El-Bustan Weather Station using the following formula:

$$ET_{crop} = ET_0 x K_c$$

Where:

ET_c = Crop water consumptive use, mm / day,

ET_0 = Reference evapotranspiration, mm / day, and

K_c = Crop coefficient

Crop coefficient for maize crop was used to calculate the (ET_c) values according to **(FAO, 1984)**. Reference evapotranspiration (ET_0), crop coefficient (K_c) and water consumptive use (ETc) for different growth stages are presented in Table (4).

Table 4. Calculated water consumptive use for maize crop.

Growth stage	ET_0, mm/day	K_c	ETc, mm/day
Initial (18/5-2/6)	6.20	0.35	2.17
Development (3/6-3/7)	7.50	0.75	4.62
Midseason (4/7-4/8)	8.10	1.15	9.30
Late season (5/8-31/8)	8.60	0.85	7.31
At harvest (1/9-10/9)	6.80	0.55	3.74

Actual water consumptive use was estimated based on the soil moisture content and calculated according to **Israelsen and Hansen (1962)** by using the following equation:

$$ET_{actual} = D(\theta_2 - \theta_1)/I$$

Where:

ET_{actual} = Actual water consumptive use, mm / day,

D = Soil depth, m,

θ_2 = Soil moisture content by weight (mm/m) after irrigation,

θ_1 = Soil moisture content by weight (mm/m) before irrigation, and

I = Period between irrigations, day.

Soil samples for estimating the actual water consumptive use were taken from three depths (0-20cm), (20-40cm) and (40-60cm) after irrigation and before the next irrigation throughout each growth stage.

4. Irrigation scheduling

Two irrigation intervals were tested in this experiment; daily irrigation (F_1) and irrigation every three days (F_2) for drip and sprinkler irrigation systems.

5. Fertilizer program

Fertilizer requirements of maize were added according to the recommendation

of the Crop Research Institute, ARC, Minestry of Agriculture and Lands Reclamation. 250kg per feddan of super phosphate (15.5% P_2O_5), 100kg per feddan of potassium sulfate (48% K_2O) were added during the seed bed preparation and 350kg per feddan of ammonium nitrate (33%N) divided into ten doses and injected through irrigation system starting from 21days after planting till the fruit stage.

6. Measurments and Calculations

1- Determine seasonal irrigation water requirements in m^3 per feddan.
2- Grain yield in Mgram per feddan (ton/fed).
3- Water use efficiency (Kg/m^3)

$$= \frac{Total\ yied(Mgram/fed)x1000}{Total\ Water\ applied\ (m^3/fed)}$$

4- Crop production function was determined from the relation between the grain yield (Mgram / fed) and the seasonal evapotranspiration (m^3 / fed).
5- Irrigation cost was computed according to the capital cost for each system, which was calculated using the current dealer prices for equipment and installation according to 2001price level.
   a- The annual fixed cost of the capital invested in the irrigation system was calculated using the following formula, (**Jensen, 1981**).

$$F.C. = S \times CRF$$

Where:
F.C.= the annual fixed cost, LE / fed,
S = the initial cost, LE/fed, and
CRF= the capital recovery factor which was calculated as follow:

$$CRF = \frac{i(1+i)^n}{(1+i)^{n-1}}$$

Where:
i = the annual interest rate (taken as 14%), and
n = the expected life time of each item, year.

b- The annual variable cost was calculated as follow:

$$V.C. = L.C. + E.C. + (R.C \& M.C)$$

Where:
V.C = the annual variable cost, LE / fed,
L.C = the labor cost, LE/fed,
E.C = the energy cost, LE/fed, and
R.C & M.C = the repair and maintenance cost, LE / fed (2% and 3% for Sprinkler and drip irrigation system).

The energy cost, LE / fed = power consumption (kW) x operation time (h) x electrical power cost (LE / k W.h).

6- Cost of production unit (LE/Mgram)

$$= \frac{Total\ irrigation\ cost(LE/fed)}{Total\ yield(Mgram/fed)}$$

7- The obtained data were analyzed statistically as split- split plot design according to **Gomez and Gomez (1984).**

RESULTS AND DICUSSION

Irrigation water requirement for maize crop

Table (5) shows that the seasonal irrigation water requirements for maize based on the climatic data was higher

than estimated values using the soil sampling method by 13.7 and 22.6% under sprinkler and drip irrigation systems respectively. Also, The results indicated that the actual seasonal irrigation water requirements under sprinkler irrigation system i.e. (1763, 2514 and 3171m3/fed) at 50, 75 and 100% of ETc respectively were higher than that under drip irrigation system (1493, 2058 and 2527 m3/fed). This may be due to the lower efficiency of sprinkler irrigation compared to the drip irrigation system. The drip irrigation system saved about 20.3% from water requirement compared to sprinkler irrigation system. This results are in agreement with both **Arnaout, 1997 and Kamal, 2000.**

Table 5. Actual and calculated irrigation water requirement for maize crop.

Irrigation System	Water requirement m^3/ fed.	Irrigation treatments		
		50% of ETc	75% of ETc	100% of ETc
Sprinkler	Calculated	1838	2757	3676
	Actual	1763	2514	3171
	Difference, %	4.10	8.80	13.70
Drip	Calculated	1633	2450	3267
	Actual	1493	2058	2527
	Difference, %	8.60	15.0	22.60

Effect of irrigation system on maize yield and water use efficiency

Figs. (2 and 3) show that the irrigation system was significantly correlated to grain yield of maize crop. Drip irrigation system produced the highest value of grain yield (4.24Mgram/fed) compared to sprinkler irrigation system that produced (3.36Mgram/fed). On the other hand, water use efficiency was highly significant affected by the irrigation system. The highest value of water use efficiency was (1.3 kg / m^3) under drip irrigation system, while the lowest value was (0.78 kg / m^3) under sprinkler irrigation system. This may be due to the preserving of high amount of available water in the root zone that is favorable for root growth and increasing the total maize yield. This results are in agreement with **(El-Gindy, 1988; Badr, 1993 and Kamal, 2000).**

Effect of irrigation intervals on maize yield and water use efficiency

Figs. (2 and 3) show that the irrigation scheduling was significantly correlated to grain yield of maize crop. The

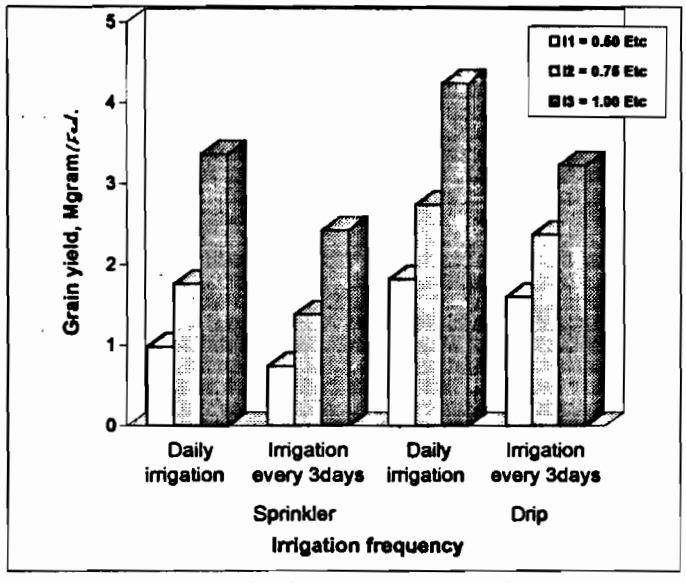

Fig.(2):Effect of irrigation frequency on maize grain yield under both sprinkler and drip irrigation systems.

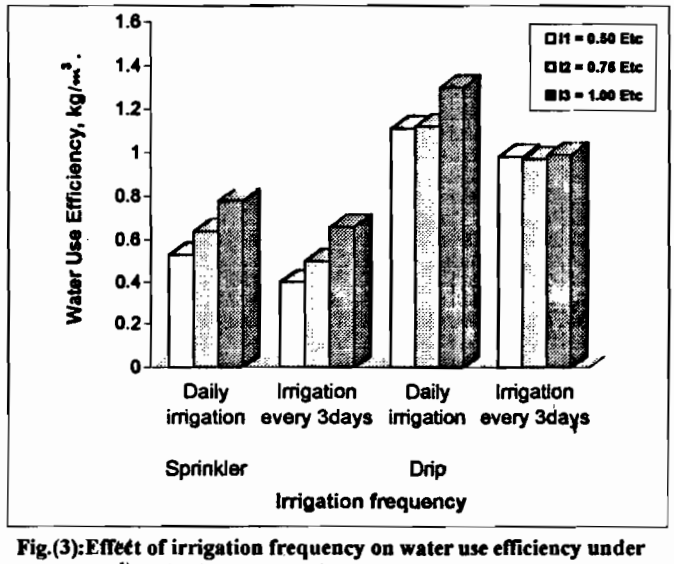

Fig.(3):Effect of irrigation frequency on water use efficiency under both sprinkler and drip irrigation systems.

highest value of grain yield were (4.24 and 3.36 Mgram / fed) by irrigating daily when using drip and sprinkler irrigation systems respectively compared with the irrigation every three days (3.23and 2.42 Mgram/fed). On the other hand, the water use efficiency was significantly affected by the irrigation scheduling. Daily irrigation drip irrigation system was the highest value of water use efficiency (1.30kg/m^3) compared to the irrigation every three days (0.99kg / m^3). The same trend was observed under sprinkler irrigation system.

Water production function

Data are illustrated in Figs. (4 and 5) indicated that the yield of maize crop was significantly affected by water application rate. The water crop function can be described by the following formulas:

For sprinkler irrigation system

Daily irrigation

$$Y = 2x\,10^{-7}X^2 - 2x\,10^{-5}X + 0.38$$

Irrigation every three days

$$Y = 2x\,10^{-7}X^2 - 4x\,10^{-4}X + 0.66$$

For drip irrigation system

Daily irrigation

$$Y = 6x\,10^{-7}X^2 - 0.0012X + 2.26$$

Irrigation every three days

$$Y = 6x\,10^{-8}X^2 - 0.0007 + 0.33$$

Where:

Y = Grain yield in Mgram / feddan, and

X = Amount applied water in m^3 / feddan.

These relationships show that when reducing the water application rate from 100% Etc (3267and 3676m^3 / fed.) to 75% Etc (2450 and 2757 m^3/fed.), the grain yield reduced by 35.4% and 47.6% under drip and sprinkler irrigation systems respectively, while the yield reduced by57% and 70.8% when reducing the water application rate from100% Etc (3267 and 3676m^3 /fed.) to 50% Etc (1633 and 1838 m^3 / fed.) under drip and sprinkler irrigation systems respectively. Also, the slope of functions under sprinkler irrigation system is less steeper in both daily irrigation and irrigation every three days than that under drip irrigation system. This results are in agreement with both **Allen *et al* 1998 and Jennifer *et al* 1999.**

Cost of production unit

Data in Table (6) indicate that the cost of maize production unit (64.6LE/ Mgram) for drip irrigated maize was lower than that under sprinkler irrigation system (74.8LE / Mgram) by 13.6%. On the other hand, the cost of production unit decreased from 140.5 to 64.6LE/ Mgram by increasing the rate of water application from 50 to 100% of ETc under drip irrigation system, while it decreased from 233.2 to 74.8LE/Mgram when using sprinkler irrigation respectively. This may be due to the increase in the yield was greater than that the irrigation cost .On the other hand, the cost of production unit with daily irrigation was lower by 27.9 and 24.1% compared to irrigation every three days under both sprinkler and drip irrigation system respectively.

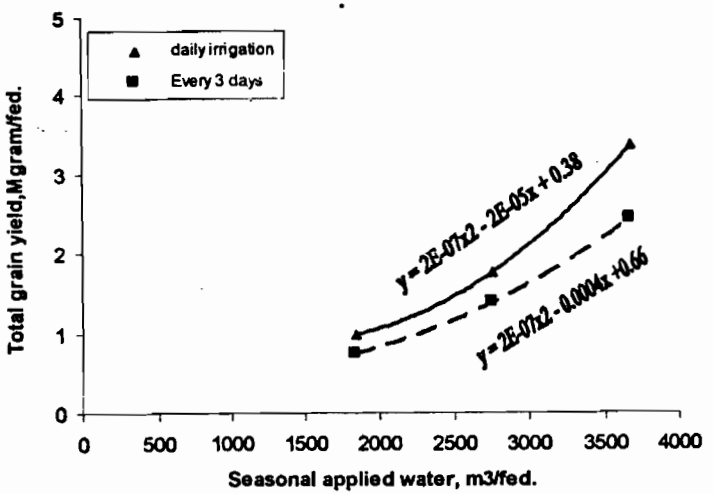

Fig. 4. The relationship between the total yield of maize and applied water under sprinkler irrigation system.

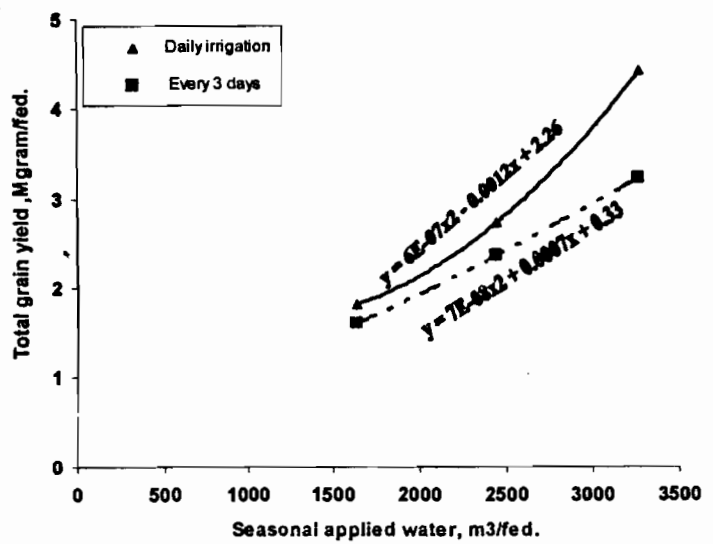

Fig. 5. The relationship between the total yield of maize and applied water under drip irrigation system.

Table 6. Maize production cost (LE/Mgram) under different irrigation treatments

Irrigation System	Irrigation treatments	Irrigation intervals					
		Daily irrigation			Irrigation every three days		
		Irr. cost LE/ fed	Yield Mgram/ fed	Unit cost LE/ Mgram	Irr. cost LE/fed	Yield Mgram/ fed	Unit cost LE/ Mgram
Sprinkler	50% ETc	228.5	0.98	233.2	228.5	0.74	308.8
	75% ETc	240.0	1.76	136.4	240.0	1.38	173.9
	100% ETc	251.3	3.36	74.8	251.3	2.42	103.8
Drip	50% ETc	255.8	1.82	140.5	255.8	1.60	160.0
	75% ETc	265.5	2.74	96.9	265.5	2.37	112.0
	100% ETc	274.8	4.24	64.6	274.8	3.23	85.1

CONCLUSION

The results obtained can be summarized as follow:

1- Actual seasonal irrigation water requirements for maize were lower by (13.7 and 22.6%) than calculated irrigation water requirements under both sprinkler and drip irrigation systems.
2- The highest grain yield (4.24M gram/ fed) was produced under drip irrigation system compared to sprinkler irrigation system (3.36 Mgram/fed).
3- The best maize yield was obtained by applying 100%of ETc under both drip and sprinkler irrigation system compared to 50 and 75% of Etc treatments
4- Daily irrigating gave the highest yield of maize compared to irrigation every three days under both sprinkler and drip irrigation system.
5- The lowest cost of maize production unit was (64.6LE/Mgram) under drip irrigation system at 100% of ETc, while the highest cost was 308.8LE/Mgram under sprinkler irrigation system at 50% of ETc.

Finally, it could be recommended the drip irrigation system with daily irrigating at 100% of ETc for irrigating maize in sandy soil for high production.

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تعظيم الاستفادة من مياه الرى لمحصول الذرة الشامية في الأراضى الرملية

[٣٣]

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لقد أولت الدولة اهتماماً كبيراً لترشيد مياه الرى وتوفير جزء من المياه لاستغلالها في استصلاح واستزراع مساحات جديدة من الأراضى. ومن أهم الوسائل لترشيد المياه هى تطبيق نظم الرى الحديثة وحسن إدارتها، لذلك أجريت هذه التجارب بمزرعة شباب الخريجين بمدينة البستان بالنوبارية مواسم (١٩٩٨ ، ١٩٩٩ ، ٢٠٠٠) على محصول الذرة الشامية (هجين فردى ١٠) تحت نظامى رى (رش وتنقيط) مع إضافة ثلاثة مستويات رى (٥٠ ، ٧٥ ، ١٠٠% من الاستهلاك المائى المحسوب)، وهذه الكميات أضيفت يومياً أو كل ثلاثة أيام.

كانت أهم النتائج المتحصل عليها من هذه الدراسة هى

١- يوفر نظام الرى بالتنقيط حوالى ٢٠,٣% من كمية المياه بالمقارنة بنظام الرى بالرش.

٢- حقق نظام الرى بالتنقيط أعلى إنتاجية (٤,٢٤ ميجاجرام / فدان) بالمقارنة بنظام الرى بالرش الذى أعطى (٣,٣٦ ميجاجرام / فدان)، بزيادة مقدارها ٢٠,٧%.

٣- الرى اليومى للذرة الشامية حقق إنتاجية أكبر منها في حالة الرى كل ثلاثة أيام.

٤- أقل تكاليف لرى الذرة الشامية (٦٤,٤ جنيه / ميجاجرام) تحت نظام الرى بالتنقيط مع إضافة ١٠٠% من الاستهلاك المائى يومياً ، بينما أعلى تكاليف رى كانت (٣٠٨,٨ جنيه / ميجاجرام) تحت نظام الرى بالرش مع إضافة ٥٠% من الاستهلاك المائى كل ثلاثة أيام.

٥- تم الحصول علي دالة الانتاج لمحصول الذرة الشامية في الأراضى الرملية تحت نظامى الرى بالرش والتنقيط وهى:

- تحت نظام الرى بالتنقيط اليومى

$$Y = 2 \times 10^{-7} X^2 - 2 \times 10^{-5} X + 0.38$$

- تحت نظام الرى بالتنقيط كل ثلاثة أيام

$Y = 2 \times 10^{-7} X^2 - 4 \times 10^{-4} X + 0.66$

- تحت نظام الرى بالرش اليومى

$Y = 6 \times 10^{-7} X^2 - 0.0012 X + 2.26$

$Y = 7 \times 10^{-8} X^2 - 0.0007 + 0.33$

- تحت نظام الرى بالرش كل ثلاثة أيام

حيث أن:

Y : كمية المحصول بالميجاجرام / فدان.

X : كمية المياه المضافة بالمتر مكعب / فدان

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